III. INDUSTRY CHARACTERIZATION

Ocean-going vessels (or "vessels") that operate within 24 nautical miles of the California coastline ("regulated waters") would be subject to the requirements of the proposed regulation. The requirements of the proposal would apply to both foreign-flagged and domestic vessels. However, exemptions are provided for military vessels and vessels passing through regulated waters without stopping at a California port ("innocent passage").

For the purposes of the proposed regulation, an ocean-going vessel is defined as a commercial or military vessel that meets any one of the following criteria:

- a U.S.-registered vessel that is used in foreign trade, and has the appropriate U.S. Coast Guard endorsement;
- a foreign-registered vessel;
- a vessel greater than 400 feet in overall length;
- a vessel greater than or equal to 10,000 gross tons; or
- a vessel propelled by a marine compression ignition engine with a per cylinder displacement of greater than or equal to 30 liters.

Vessels meeting none of these criteria are classified as harbor craft (including pleasure craft), and are subject to more stringent fuel requirements than those specified in this proposal.[1]

In this chapter, we identify the types of vessels that are defined as ocean-going vessels, and also describe the types of engines and fuels currently being used by these vessels. Additional information on this industry can also be found in the U.S. EPA's Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder. (U.S. EPA, 2003).

This section also identifies and summarizes the requirements of existing air pollution regulations that affect ocean-going vessels.

A. Vessel Descriptions

Examples of the types of oceangoing vessels subject to the proposed regulation include container vessels, passenger cruise vessels, general cargo, reefers, RORO vessels, tanker vessels, and bulk carriers. Brief descriptions of these vessel types are provided below.

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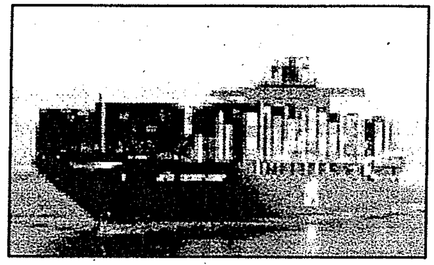
[1] Specifically, only diesel fuel meeting CARB vehicular diesel fuel standards will be sold to harbor craft in California in 2007 (2006 in the South Coast Air Quality Management District).

Container Vessels

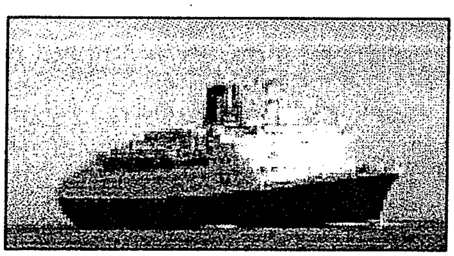


Container vessels are cargo vessels that carry standardized truck-sized containers. These containers have capacities measured in TEUs (Twenty-foot Equivalent Units). One TEU refers to a container with external dimensions of 8'x8'x20'. Capacity is sometimes also measured by FEU's, forty-foot equivalents, 8'x8'x40', since the majority of containers used today are 40 feet in length. Many vessels also have a number of container slots that will accept refrigerated containers.

Container vessel capacity is often described in terms of the number of TEU's the vessel can hold. Due to economies of scale, container vessel capacity has increased over the years. Currently, some large vessels are able to transport between 5,000 and 8,000 TEUs. This compares to older vessels built prior to 1970, which typically held less than 1,000 TEUs.

Most container vessels, like most ocean-going vessels, are propelled by large slow-speed two-stroke direct drive diesel engines (see figure 2). In addition, most container vessels have installed a number of smaller medium speed four-stroke auxiliary engines. The auxiliary engines, which are subject to the proposed regulation, provide electrical power for lighting, navigation equipment, and other ship-board uses.

Passenger Cruise Vessels



Passenger cruise vessels are passenger vessels used for pleasure voyages. These vessels typically stop at ports, where they coordinate activities for their passengers. Passenger cruise vessels also provide a number of entertainment options for their passengers while on the vessel. These vessels typically include swimming pools, exercise and recreation facilities, movie theaters, dance halls, casinos, and restaurants. As with other types of vessels, the size and capacity of these vessels has increased steadily over the years.

Table III-1: Typical Size of Passenger Cruise Vessels Over the Years

Year Built	Tonnage	Number of Passengers
1970	18,420	377 passengers
1980	37,600	707 passengers
1990	74,140	975 passengers
2000	137,300	1557 passengers

(Solentwaters, 2005)

Cruise ship propulsion is typically provided by several diesel engines coupled to generators. These generators produce electrical power that drives electric motors coupled to the vessel's propellers. This arrangement provides the option to run the vessel at a slower speed, while operating fewer engines at their peak efficiency, as opposed to a single engine at low, relatively inefficient loads. The same engines that are used for propulsion are also used to generate auxiliary power onboard the vessel for lights, refrigeration, etc.

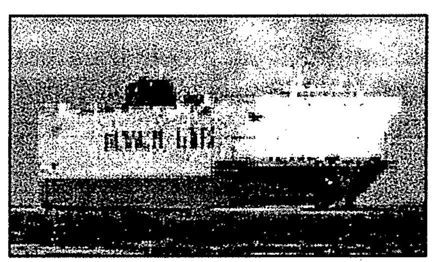
Some vessels have the electric motor outside the ships hull in an azipod. This method eliminates the need for a rudder as the pod can be rotated to provide thrust in any direction. Some vessels also have a combination of a fixed propeller and azipods.

<u>Reefer Vessels</u>

A Reefer vessel is a type of vessel typically used to transport perishable commodities which require temperature-controlled transportation, mostly fruits, meat, fish, vegetables, dairy products, and other foods. Reefer vessels are effectively large refrigerators, heavily insulated with glass fiber or similarly efficient insulation. They are vessels that tend to be divided into many more spaces than conventional dry cargo vessel, so that different commodities can be separated and carried, if required, at different temperatures. Below deck, a reefer vessel resembles a large modern warehouse, and cargo is usually carried and handled in palletized form, moved about on conveyors or by electric fork lift trucks.

<u>RORO Vessels</u>

A RORO vessel carries wheeled cargo such as automobiles, trailers or railway carriages. RORO is an acronym for "roll on/roll off". RORO vessels have built-in ramps, which allow the cargo to be "rolled on" and "rolled off" the vessel when in port. While smaller ferries that operate across rivers and other short distances often have these facilities, the term RORO is generally reserved for ocean-going vessels.



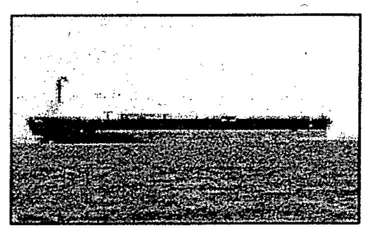
Typically new automobiles that are transported by vessel around the world are moved on ROROs. These large new-car carriers are commonly called Pure Car Carriers (PCCs) or Pure Car Truck Carriers (PCTCs). The largest PCC currently in service can carry over 7000 cars.

Bulk Carriers

Bulk carriers are vessels used to transport bulk items such as mineral ore, fertilizer, wood chips, or grain. They have large box-like hatches on their deck, designed to slide outboard for loading.

The bulk carriers primarily carry dry cargoes, which are shipped in large quantities and do not need to be carried in packaged form. The principal bulk cargoes are coal, iron ore, bauxite, phosphate, nitrate and grains such as wheat. The advantage of carrying such cargoes in bulk is that packaging costs can be greatly reduced and loading and unloading operations can be speeded up.

Tanker Vessel



Tanker vessels are vessels designed to transport liquids in bulk. Tankers can range in size from several hundred tons, designed for coastal service, to several hundred thousand tons, for transoceanic voyages. A wide range of products are carried by tankers, including:

- hydrocarbon products such as crude oil, LPG, and LNG
- chemicals, such as ammonia, chlorine, and styrene monomer; or
- fresh water

Different products require different handling and transport, thus special types of tankers have been built, such as "chemical tankers," "oil tankers," and "LNG carriers."

B. Vessels That Visit California Ports

California is a key player in international shipping. All of the vessel types described previously visit California ports delivering and receiving products used in California, the United States, and the rest of the world. As shown in Table III-2 below, container vessels accounted for nearly half of the California port visits in 2004, followed by tankers at 19 percent of port visits. The remaining categories of vessels each account for less than ten percent of vessel visits.

Table III-2: 2004 California Port Calls by Vessel Type

Vessel Type	Number of Calls	Percentage of Total Calls
Container Vessels	4,545	48%
Tankers	1,811	19%
Bulk Carriers	885	9%
Auto Carriers (RORO)	713	8%
General Cargo/Reefers	685	7%
Passenger Cruise Vessel	652	7%
Barge	106	1%
Other	44	<1%
Total	9,441	100%

(California State Lands Commission, 2004)

Table III-3 ranks California's ports by the number of vessel visits. As shown in the table, over 50 percent of port calls occurred at the Ports of Los Angeles and Long Beach (which are adjacent to each other). The Port of Oakland accounted for about 19 percent of the port calls, and the remaining ports individually received 5 percent or less of the vessel calls.

Table III-3: 2004 Port Ranking by Vessel Visits

Port	Number of Calls	Percentage of Total Calls
Los Angeles/Long Beach	5,083	54%
Oakland	1,797	19%
Richmond	491	5%
Carquinez	463	5%
San Diego	447	5%
Hueneme	318	3%
San Francisco	300	3%
El Segundo	205	2%
Stockton	133	2%
All Other	203	2%
Total	9,441	100%

(California State Lands Commission, 2004)

C. Auxiliary Engines and Fuels

The following sections describe the types of engines currently being used by ocean-going vessels. The information presented below was reported by vessel owners and operators in response to ARB's *Oceangoing Ship Survey* or "Survey" (January 2005). The Survey requested information only for oceangoing vessels that visited California ports in 2004. Data was provided on approximately 327 vessels and over 1,400 engines. For more detailed Oceangoing Ship Survey data, see Appendix C.

Most of the ocean-going vessels subject to the proposed regulation have both main propulsion (main engines) and auxiliary diesel engines. The main engine for most vessels is a diesel-mechanical propulsion system, where the diesel engine is directly coupled to the propeller through a transmission. The exception is passenger cruise vessels and a few tankers, where the main engines are coupled to electric generators which provide electric power to electric motors which are directly coupled to the propellers. These are referred to as diesel-electric systems.

In most cases, the auxiliary engines provide power for uses other than propulsion. Most auxiliary engines are part of a diesel-electric system that is used to provide power for a variety of on-board systems including lighting systems, onboard cargo handling equipment, heating and air conditioning systems, and emergency power. Many passenger cruise vessels that have diesel-electric propulsion systems use the main engines to power electric motors that perform the same functions as auxiliary engines. Because of the relatively high electrical energy draw aboard a passenger cruise vessel, some also have gas turbine-electric systems aboard. Below we provide summaries of selected data collected from the Survey with an emphasis on auxiliary engine information.

Auxiliary Engines

All vessel owners responding to the Survey reported at least one auxiliary engine. Table III-4 summarizes the quantity of auxiliary engines the Survey reported. The majority of the auxiliary engines are diesel compression ignition engines and all of the auxiliary engines reported are four-stroke engines. A four-stroke engine completes one power cycle for every two revolutions of the crankshaft. Therefore, there is one power stroke for every two revolutions of the crankshaft. The four-strokes include: intake, compression, power, and exhaust. The tables listed below provide more information on auxiliary engines on oceangoing vessels.

Table III-4: Number of Auxiliary Engines

Vessel Type	Minimum Number of Auxiliary Engines	Maximum Number of Auxiliary Engines	Average Number of Auxiliary Engines
Passenger/Cruise	3	6	4.7
Reefer	4	4	4
Auto Carrier	2	4	2.9
Container	2	6	3.6
Tanker	1	6	2.7
Other	2	4	2.9

Tables III-5 and III-6 provide information on the type of fuel used to power the auxiliary engines and the average sulfur content of that fuel. According to the Survey, 25 percent of the auxiliary engines already use distillate fuel. The sulfur content of the distillate ranges from 0.03 – 1.5 percent with an average sulfur content of 0.5 percent.

Table III-5: Auxiliary Engine Fuels

Fuel Used in Auxiliary Engine	Number of Engines Reporting in Survey	Percent of Total Engines
Heavy Fuel Oil	877	75%
Distillate Fuel	294	25%

Table III-6: Average Sulfur Content of Fuel Used in Ocean-going Auxiliary Engines

Fuel	Minimum Sulfur Content (%)	Maximum Sulfur Content (%)	Average Sulfur Content (%)
Heavy Fuel Oil	0.15%	4.0%	2.5%
Distillate	0.03%	1.5%	0.5%*

* 0.5 for compression-ignition engines only (excludes turbines which use low sulfur fuel).

The manufacturers of the auxiliary engines were numerous, but five manufacturers accounted for almost 90 percent of the engines reported. These manufacturers are shown below in Table III-7.

Table III-7: Ocean-going Vessel Auxiliary Engine Manufacturers

Engine Maker	Number of Engines	Percent of Total Engines
Man B&W	324	29%
Daihatsu	251	22%
Wartsila/Sulzer	249	22%
Yanmar	118	10%
MAK	44	4%
Other	151	13%

Figure III-1 shows the distribution in age of the auxiliary engines. It is interesting to note that a large percentage of the auxiliary engines are less than 10 years old. Typically, the auxiliary engines last the life of the vessel, so the age distribution of these engines is similar to the age distribution of vessels visiting California ports.

Figure III-1: Ocean-going Vessel Auxiliary Engine Age Distribution

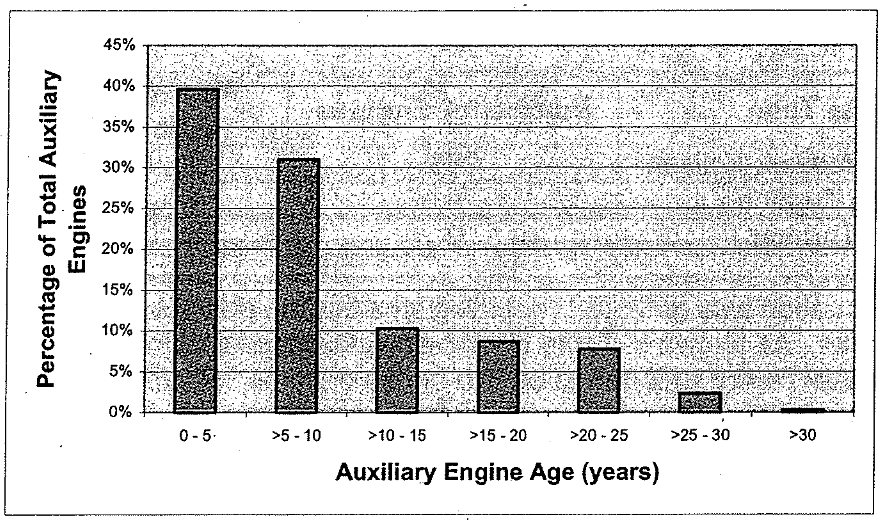


Table III-10 provides information on the average power generated by the auxiliary engines when vessels are hotelling (dockside), maneuvering at ports, and transiting at sea. The diesel generator set engines on passenger cruise vessels are defined as "auxiliary engines" for the purposes of the proposed regulation. The power generated by these engines is much higher than for other vessels because these engines produce electrical power for both propulsion and ship-board electricity.

Table III-8: Average Power Generated

Type of Vessel	Power Generated While Hotelling (kw)	Power Generated While Maneuvering (kw)	Power Generated While At Sea (kw)
Passenger/Cruise	7,500	13,800	34,000
Container	1,600	3,300	3,800
Other	1,450	1,700	4,200
Auto Carrier	600	1,300	580
Tanker	500	660	480
Reefer	1,200	1,200	2,000
Average All Vessels	2,000	3,420	6,600

Main Engines

According to the Survey, as reported in Table III-9, main engines are dominated by diesel engines, with only a small fraction being either gas or steam turbine. The diesel piston engines used on vessels are reciprocating internal combustion engines that operate on the same basic principles as land-based diesel engines. The main engine type results are shown below.

Table III-9: Main Engine Types

Engine Type	Number of Engines	Percent of Total Main Engines
Diesel Compression-Ignition	289	96%
Steam Turbine	9	3%
Gas Turbine	2	1%

Additional information was gathered regarding whether the diesel engines were either two or four-stroke. As shown in Table III-10 below, 95 percent of the main engines on oceangoing vessels were reported to be two-stroke engines. Reciprocating internal combustion engines may operate in a two or four-stroke cycle, where a stroke is one complete movement of the piston from one end of the cylinder to the other. Two stoke engines have higher horsepower to weight ratio than four-stroke engines, but two-stroke engines tend to have higher NOx emissions. According to the survey, main engines use primarily heavy fuel oil.

Table III-10: Diesel Main Engine Types

Diesel Engine Type	Number of Engines	Percent of Total Diesel Engines
2-stroke	271	95%
4-stroke	15	5%

D. Vessel Fuels and Fuel Systems

As explained in Section B, most oceangoing vessels are propelled by a single large slow-speed two-stroke direct drive diesel engine, with smaller medium speed four-stroke auxiliary engines providing electrical power for lighting, navigation equipment, and other ship-board uses. For these vessels, the large main engine almost always operates on heavy fuel oil (HFO), while the smaller auxiliary engines may run on either HFO or marine distillate fuels such as marine gas oil or marine diesel oil. Vessels that use HFO in both their main and auxiliary engines are referred to as mono-fueled (or uni-fueled) vessels, while vessels that use distillate fuels in their auxiliary engines are referred to as dual-fueled.

Diesel-electric vessels such as passenger cruise vessels use very large four-stroke medium speed engines coupled to generators to provide electrical power for both propulsion and ship-board electrical power. These vessels generally use HFO, although some have reported using marine distillate fuels close to shore to reduce their emissions.

Fuel Types

The two basic types of marine fuels are distillate and residual. Distillate fuel is composed of the lighter fractions of crude oil that are separated in a refinery by a boiling process, while the remaining fraction that did not boil is referred to as residual.

Distillate Marine Fuels

The two most common types of marine distillate fuels are marine gas oil (MGO) and marine diesel oil (MDO). MGO is also referred to as DMA using official fuel specification terminology, where the "D" denotes a distillate fuel, the "M" indicates a marine fuel, and the "A" is the grade of fuel. MDO is similar to MGO, but may have a somewhat higher viscosity and sulfur content. This fuel is also referred to as DMB using official terminology, with the same nomenclature as for DMA fuel. MDO is generally MGO that contains a limited amount of residual fuel from storage in tanks or piping that previously held residual fuel. Other types of distillate marine fuels include DMX and DMC fuels. DMX fuel is special grade of fuel generally used only in emergency backup generators, while DMC is a distillate fuel like DMB, except that it is intentionally manufactured from heavier boiling fractions from a distillation process, or is blended from DMA and residual fuels. (U.S. EPA, 1999).

Residual Fuels

Marine residual fuel (also called "heavy fuel oil") is generally a mixture of residual and distillate fuels referred to as intermediate fuel oil (IFO). While there are numerous grades of marine residual fuels, the most common types are IFO-180 and IFO-380. Using this informal terminology, the numbers used in naming these fuels refers to the viscosity limits at the common fuel handling temperature of 50°C. Similar to the distillate fuels, there is also a parallel official terminology. For example, IFO-380 fuel is referred to as either RMG-35 or RMH-35. Using this terminology the "R" denotes a residual fuel, the "M" denotes a marine fuel, and the "35" is the maximum viscosity at 100°C. (U.S. EPA, 1999)

Listed below in Table III-11 are the common marine fuels discussed above, and the range in their allowable properties.

Table III-11: Selected ASTM Specifications for Marine Fuels

	Distillate Fuels		HFO/Residual Fuels	
Specification	**MGO (DMA)**	**MDO (DMB)**	**IFO 180 (RME/F-25)**	**IFO 380 RMG/H-35**
Min. Flash Pt. (°C)	60	60	60	60
Kinematic Viscosity (cSt@40°C)	1.5-6	11 max	25 *	35*
Max % Sulfur (wt.)	1.5	2.0	5.0**	5.0**
Max. % Ash (wt.)	0.01	0.01	0.10-0.15	0.15-0.2
% Distillate	100	99+	12	2

* Viscosity in centistokes at 100°C, ** IMO Annex VI limits sulfur to 4.5%.

Fuel Handling

Ocean-going vessels have complex fuel handling and processing systems that vary with the individual vessel. Most have multiple fuel storage tanks that can hold various grades of fuel, both distillate and HFO. Marine fuels undergo several processes before they are combusted in the engine. Typically, fuel from the storage tank is: (1) pumped to a settling tank; (2) pumped to a centrifuge for removal of water and sludge; (3) pumped to service (day) tank; and (4) pumped to the engine for consumption. Depending on the vessel, there are different ways these processes are handled, some with complete segregation of fuel processes for different grades of fuel, and some utilizing the same fuel processing components for different grades of fuel (Marintek, 2003). In addition, the complete fuel handling system will include additional filtration, venting, drainage, and other components.

The fuel processing steps mentioned above apply to both HFO and distillate fuels. However, heavy fuel oil must also be heated to 100 to 200 degrees Celsius to reduce its viscosity to a point where it can be pumped and combusted in the engine. Because HFO is so viscous, vessel operators switch to distillate marine fuels prior to vessel dry-dock maintenance operations so that this fuel does not solidify in pipes and components when the engine is stopped.

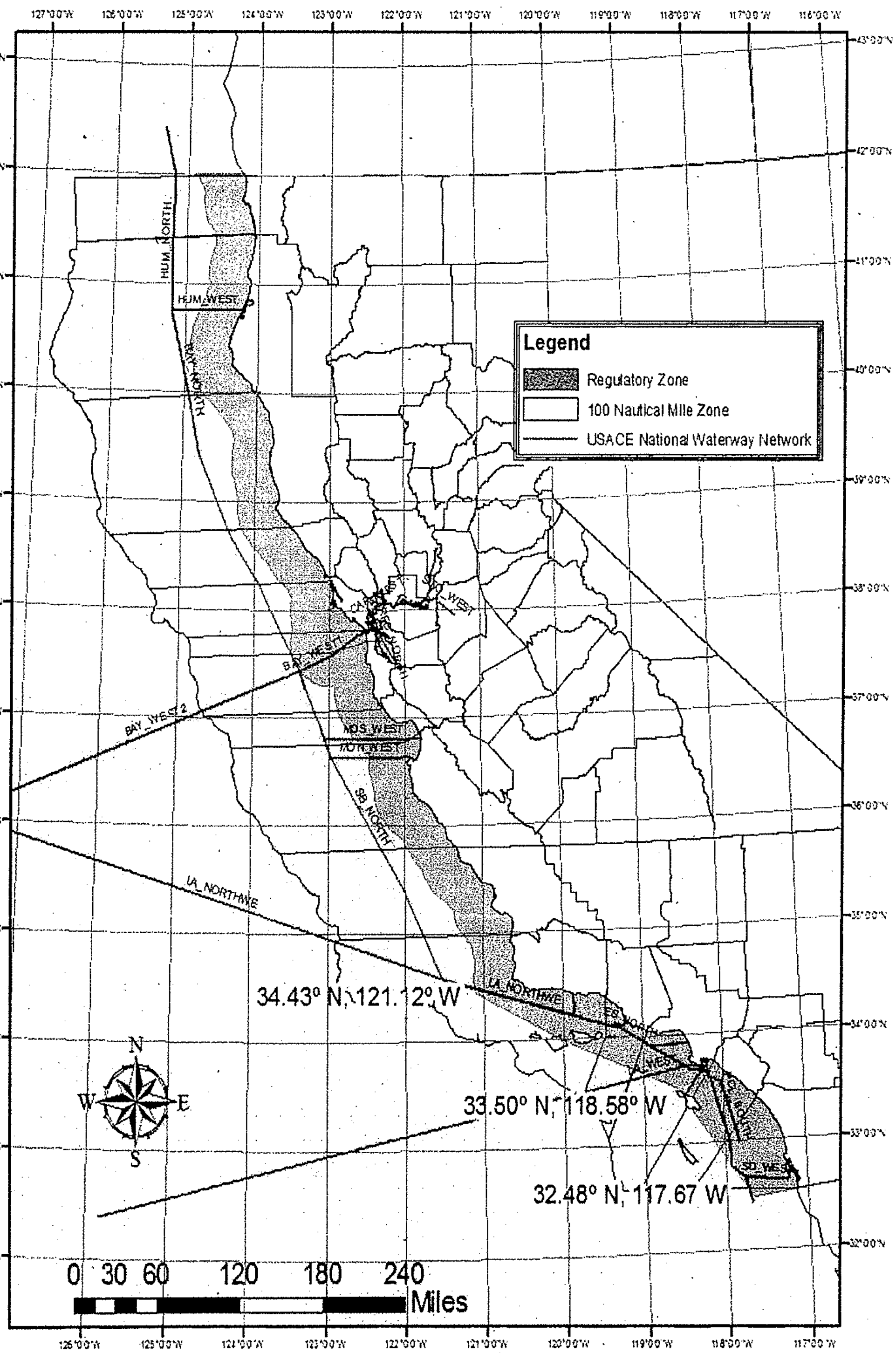
E. The Shipping Lanes and Ocean-going Vessel Activity Off the Coast of California

The coastline of California stretches more than 800 miles, from Mexico in the south to Oregon in the north. In 2004, California's ports were visited by more than 1,900 ocean-going vessels. These vessels made approximately 10,000 visits to one or more of California's deep-water ports.

Ships typically travel in designated shipping lanes in high traffic areas near California's ports. For example, there are designated shipping lanes that oceangoing vessels use within the Santa Barbara Channel and approximately 25 nautical miles south of the

Ports of Los Angeles and Long Beach. (Marine Exchange of Southern California). Similarly, there are designated shipping lanes within the San Francisco Bay and surrounding areas north to approximately Point Reyes, west to the Farallon Islands, and south to Half Moon Bay. (Marine Exchange of San Francisco). Outside of the port areas, vessels are generally free to choose their routes, although certain vessel-specific requirements may apply. For these low traffic areas, approximations must be made of the most likely routes. To approximate the routes used by oceangoing vessels off California's coastline, including both designated shipping lanes and other areas, ARB staff used the "United States Army Corps of Engineers (USACE) Shipping Lanes," as shown in Figure III-2.

Figure III-2: USACE Shipping Lanes Off the Coast of California and the 24 nm Contiguous Zone



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